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Artificial Neural Network and Mathematical Modelling of the Microwave Drying of Banana Peel Biomass

***Agbede, O.O., Eniola, G.R., Omotola, K.A., Aworanti, O.A., Agarry, S.E., Alagbe, S.O., Alade, A.O., Afolabi, T.J. and Adebayo, G.A.**

Department of Chemical Engineering, Ladoke Akintola University of Technology, PMB 4000, Ogbomoso, Oyo State, Nigeria.
*ooagbede@lautech.edu.ng; oaaworanti@lautech.edu.ng

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ABSTRACT

Fresh banana peels can be converted into bioproducts, biofuels and bioenergy. However, the high moisture content of the peel causes its deterioration and limits efficiencies of thermochemical processes for biofuels and bioenergy production. Hence, the microwave drying characteristics of banana peel was investigated. Banana peel slices were dried in a microwave oven at 200-1000 W and the effective moisture diffusivity, activation energy as well as drying energy requirement were determined. Thin layer drying mathematical and artificial neural network models were fitted to the drying data to describe the drying kinetics. The drying rate and effective moisture diffusivity increased while the energy required for drying decreased with increasing microwave power. The drying occurred mainly in the falling rate period. The effective moisture diffusivities were $1.26 \times 10^{-9} – 1.83 \times 10^{-8}$ m^2 s^{-1} at 200 – 1000 W. The activation energy was 129 $Wg^{-}1$ while the total and specific energies required for the microwave drying were 0.17 - 0.37 kWh and 48.2 – 107.5 kWh/kg water removed, respectively. The Weibull mathematical model and an artificial neural network model, which had a single-hidden layer network with 3 neurons in the hidden-layer, well described the microwave drying kinetics of the banana peel biomass.

1. INTRODUCTION

Banana is a fruit crop which belongs to the family Musaceae (Mohapatra et al., 2010). It is grown for consumption as snacks or for processing into other consumer products (Mohapatra et al., 2011). A large quantity of peels, about 30 – 40% of the weight of the fresh banana fruit, are generated when banana is consumed or processed which can cause waste disposal and environmental pollution challenge (Guerrero et al., 2016; Pathak et al., 2016). Interestingly, banana peel can be processed into value-added products (Mohapatra et al., 2010; Pathak et al., 2016) which include animal feeds (Pathak et al., 2016; Hassan et al., 2018), dietary fiber (Ramli et al., 2009; Eshak, 2016; Sharma et al., 2016), biofuels (e.g. bioethanol, biogas, bio-oil, bioethanol, biochar, synthesis gas and briquette) and bioenergy (He et al., 2020; Karimibavani et al., 2020; Selvarajoo et al., 2020). Also, biofertilizer, pectin, antioxidative substance, antibacterial compounds, cellulose nanofibers can be obtained from banana peels (Emaga et al., 2008; Padam et al., 2014; Tibolla et al., 2014; Pathak et al., 2016; Tibolla et al., 2018). Besides, banana peel can be processed into adsorbents which can be used for the removal of pollutants including dyes, heavy metal ions, oils, pesticides and organic compounds from wastewater (Anwar et al., 2010; Anastopoulos and Kyzas, 2014; El-Din et al., 2018; Ahmad and Danish, 2018; Mahindrakar and Rathod, 2018).

It is essential to remove moisture from banana peel prior to storage through drying as this will prevent its deterioration due to microbial and enzymatic activities and also reduce the costs of packaging and transportation (Mujumdar and Law, 2010). Also, the conversion of banana peel to biofuels and bioenergy through torrefaction, pyrolysis, gasification and direct combustion, requires a drying step to ensure high efficiencies of these processes because the high moisture content of the fresh peel limits the efficiencies of these thermochemical conversion processes (Hughes and Larson, 1998; McKendry, 2002; Demirbas, 2004; He et al., 2020). Moreover, the production of briquettes, adsorbents, dietary fibers and livestock feeds from banana peels requires a drying operation for the removal of moisture from the fresh peel (Katongole et al., 2011; Ahmad and Danish, 2018; Mitan and Sa'adon, 2019; Karimibavani et al., 2020). Therefore, it is essential to investigate the drying characteristics of banana peels biomass.

Drying in open sun or direct sunlight is the traditional method for drying agro-products. This technique employs the abundant and free energy from the sun, hence it is inexpensive. However, open sun drying depends on the weather condition, takes a long drying time and the material is exposed to insects, rodents, dust and rainfall. On the other hand, microwave drying employs electromagnetic microwaves to heat the material internally thereby causing a quick evaporation of water as a result of the rapid absorption of microwave energy by water molecules (Rattanadecho and Makul, 2015). Hence, faster drying rates can be achieved by microwave drying compared to open sun drying (Agbede et al., 2020a). The drying of banana peel biomass in direct sunlight as well as passive and active solar dryers have been previously reported (Agbede et al., 2022). However, the microwave drying of banana peel has not been adequately investigated. Anuar et al. (2019) have reported the effect of microwave heating on banana peel powder, but the kinetics of microwave drying was not investigated. Likewise, the mass and heat transfer properties (e.g. effective moisture diffusivity, drying activation energy and drying energy requirement) of the peel, during microwave drying, which are essential for the design and operation of industrial scale dryers, have not been reported yet in the literature.

Thin layer drying mathematical models are useful for the design, operation, optimization and control of drying processes; they have been used to describe the drying behavior of agro-products and agro-industrial residues biomass (Agbede et al., 2019a; Agbede et al., 2019b; Agbede et al., 2020b). They can be used to estimate drying times (Akpinar and Bicer, 2008). Likewise, artificial neural network models can be used to predict the drying kinetics of agro-materials (Sarimeseli et al., 2014; Aghbashlo, et al., 2015; Agbede et al., 2022).

Hence, this study aimed to determine the microwave drying characteristics of banana peel biomass, including the drying rates, effective moisture diffusivities, activation energy, drying energy requirement as well as the thin layer drying mathematical model that best describe the drying process. It also investigated the modelling of microwave drying kinetics of banana peel biomass by artificial neural network.

O.O. Agbede et al. / Nigerian Research Journal of Engineering and Environmental Sciences
8(1) 2023 pp. 1-17

2. MATERIALS AND METHODS

2.1. Sample Collection and Preparation

Fresh bananas were procured from a local market in Ogbomoso, Nigeria. The bananas were wiped clean then the peels were removed from the pulp and cut into 1.5 cm by 1 cm sizes. The peels were 4 mm thick.

2.2. Experimental Procedure for Microwave Drying

A microwave oven (M945, Hisense Electronics Ins.) which has a maximum output of 1000 W at 2450 MHz was used for the microwave drying experiments. Banana peel slices of initial mass of 4 g were spread on the rotating glass plate of the microwave oven and dried at 200 W. The peel slices were brought out of the oven and weighed at 10 min interval until a constant mass was achieved. A digital weighing balance (Alsep EX 2000A, Germany) with an accuracy of 0.01 g was used to measure the mass of samples. The microwave drying experiments were also conducted at 400, 600, 800 and 1000 W. Experiments were carried out in triplicates.

2.3. Analysis of Microwave Drying Data

The moisture content of the banana peel at time *t*, X_t (g water. g dry matter^{-1}) was defined as:

$$X_t = \frac{m_t - m_d}{m_d} \tag{1}$$

where m_t and m_d are mass (g) of the banana peel at any time t and mass (g) of absolutely dried peel sample, respectively. The moisture content can be transformed into a dimensionless moisture ratio (M_R):

$$M_R = \frac{X_t - X_e}{X_i - X_e} \tag{2}$$

where X_t and X_e are initial and equilibrium moisture contents, respectively. The values of X_e are small compared with X_t and X_i for a long drying period, so the moisture ratio can be simplified to (Perea-Flores et al., 2012; Agbede et al., 2020a):

$$M_R = \frac{X_t}{X_i} \tag{3}$$

The banana peels were dried at a drying rate:

$$D_R = \frac{X_t - X_{t+dt}}{dt} \tag{4}$$

where D_R is the drying rate (g water/g dry matter. min), X_{t+dt} is moisture content at time $t+dt$ (g water. g dry matter^{-1}) and dt is time increment (min). When drying occurs in the falling rate period, mass transfer of moisture within the banana peels controls the drying rate; hence, the diffusion of moisture within the peels can be described by the Fick's second law of diffusion (Erbay and Icier, 2010). This law can be written in terms of the moisture ratio as:

$$\frac{dM_R}{dt} = D_{eff} \frac{d^2 M_R}{dx^2} \tag{5}$$

where D_{eff} is the effective moisture diffusivity (m^2 s^{-1}) and x is spatial dimension (m). Banana peel slices have a slab geometry, so if a one-dimensional moisture transfer in an infinite slab, uniform initial moisture distribution, constant moisture diffusivity, negligible shrinkage and negligible external resistant are assumed; the solution of Equation (5) given by Crank (1975) is:

$$M_R = \frac{8}{\pi^2}\sum_{i=0}^{\infty}\frac{1}{(2i+1)^2}\exp\left[\frac{-(2i+1)^2 D_{eff}\pi^2 t}{4L^2}\right] \quad (6)$$

In the series expansion of Equation (6), the first term provides a good estimate to the solution for sufficiently long drying time (Di Scala and Crapiste, 2008):

$$M_R = \frac{8}{\pi^2}\exp\left[\frac{-D_{eff}\pi^2 t}{4L^2}\right] \quad (7)$$

where L is half of the thickness of the slab (m) and t the drying time. Equation (7) can be expressed in a linear form as:

$$In(M_R) = In\left(\frac{8}{\pi^2}\right) - \left(\frac{D_{eff}\pi^2 t}{4L^2}\right) \quad (8)$$

A straight line is obtained from the plot of ln(M_R) versus t. The effective moisture diffusivity is calculated from the slope (S_1):

$$S_1 = -\frac{D_{eff}\pi^2}{4L^2} \quad (9)$$

The microwave power dependence of the effective moisture diffusivity can be described by an Arrhenius-type relationship (Agbede et al., 2020a; Agbede et al., 2021):

$$D_{eff} = D_o \exp\left[\frac{-E_a m}{P}\right] \quad (10)$$

where D_o is the Arrhenius or pre-exponential factor (m^2 s^{-1}), E_a the activation energy (W g^{-1}), P the microwave power (W) level and m the mass (g) of fresh banana peel slice. A linear form of Equation (10) is:

$$In\ D_{eff} = In\ D_o - \frac{E_a m}{P} \quad (11)$$

The activation energy E_a can be determined from the slope (S_E) of the straight line obtained from the plot of lnD_{eff} versus m/P:

$$S_E = E_a \quad (12)$$

The total energy E_t (kWh) and specific energy E_{sp} (kWh/kg banana stalk) required for microwave drying of fresh banana peel slices were computed from Equations (13) and (14), respectively:

$$E_t = P \times D_t \quad (13)$$

$$E_{sp} = \frac{E_t}{m_i - m_d} \quad (14)$$

where P is microwave power (kW) and D_t is the total drying time (h), m_i is initial mass of the banana peel slice (kg) and m_d is mass of the absolutely dried banana peel slice (kg).

2.4. Mathematical Modelling of Thin Layer Drying Kinetics

The mathematical models fitted to the experimental drying data to describe the thin layer microwave drying of banana peel slices are shown in Table 1. The experimental data were fitted to the models by nonlinear regression analysis using the Statistical Package for the Social Sciences (SPSS) version 20 software (SPSS Inc., Chicago, Illinois). The models in Table 1 are among those that have been reported to most frequently well describe the drying data of agricultural produce (Kucuk *et al*., 2014). The statistical parameter used as criteria to determine the model that best fitted the microwave drying data were the coefficient of determination (R^2), sum of square error (SSE), root mean square error (RMSE) and Chi-square (χ^2). The model that best described the experimental data was one that had the highest value of R^2 and lowest values of SSE, RMSE and χ^2 (Kucuk *et al.*, 2014). The values of SSE, RMSE and χ^2 were calculated from Equations 15, 16 and 17, respectively, using Microsoft Excel, while R^2 values were computed and reported by SPSS software.

$$SSE = \frac{1}{N}\sum_{i=1}^{N}\left(M_{R_{\exp,i}} - M_{R_{pred,i}}\right)^2 \tag{15}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(M_{R_{pred,i}} - M_{R_{\exp,i}}\right)^2\right]^{\frac{1}{2}} \tag{16}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(M_{R_{\exp,i}} - M_{R_{pred,i}}\right)^2}{N - z} \tag{17}$$

Where $M_{Rexp,}$, $M_{Rpred,i}$, N and z are experimental moisture ratio, predicted moisture ratio, number of observations and number of constants, respectively.

Table 1: Mathematical models for the description of the thin layer drying kinetics of banana peel

No	Model name	Model equation	References
1	Midilli-Kucuk	$M_R = a\exp\left(-kt^n\right) + bt$	Midilli *et al.* (2002)
2	Page	$M_R = \exp\left(-kt^n\right)$	Page (1949)
3	Logarithmic	$M_R = a\exp\left(-kt\right) + c$	Chandra and Singh (1995)
4	Two-term	$M_R = a\exp\left(-k_0 t\right) + b\exp\left(-k_1 t\right)$	Henderson (1974), Glenn (1978)
5	Wang and Singh	$M_R = 1 + at + bt^2$	Wang and Singh (1978)
6	Approximation of diffusion	$M_R = a\exp\left(-kt\right) + \left(1-a\right)\exp\left(-kbt\right)$	Kaseem (1998)
7	Modified Henderson and Pabis	$M_R = a\exp\left(-kt\right) + b\exp\left(-gt\right) + c\exp\left(-ht\right)$	Karathanos (1999)
8	Modified Page	$M_R = \exp\left(-(kt)^n\right)$	White *et al.* (1978)
9	Henderson and Pabis	$M_R = a\exp\left(-kt\right)$	Henderson and Pabis (1961)
10	Two-term exponential	$M_R = a\exp\left(-kt\right) + \left(1-a\right)\exp\left(-kat\right)$	Sharaf-Eldeen *et al.* (1980)
11	Verma	$M_R = a\exp\left(-kt\right) + \left(1-a\right)\exp\left(-gt\right)$	Verma *et al.* (1985)
12	Weibull	$M_R = a - b\exp\left(-kt^n\right)$	Weibull (1951)

2.5. Artificial Neural Network (ANN) Modelling Procedure

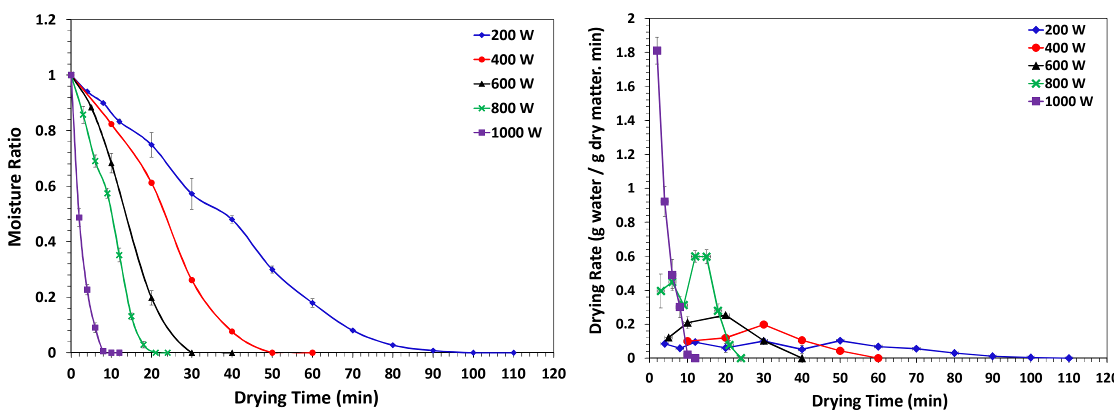
The multilayer perceptron (MLP) ANN with a feed forward-back propagation structure using Levenberg-Marquardt training algorithm has been reported to best describe the drying rates of agro-products (Sarimeseli et al., 2014); so this method was employed in this study. The number of nodes in the input layer is determined by the number of independent variables while the number of neurons in the output layer is determined by the number of dependent variables (Kim, 2017). In this study there was one dependent variable (the moisture ratio) and one independent variable (time), so one neuron was allocated to the output layer and one node to the input layer. However, the number of hidden layers and their neurons were varied by trial and error until the desired prediction accuracy was achieved. To select the best network topology two evaluation factors were used: the highest value of correlation coefficient (R), and the least mean squared of errors (MSE). The neurons of the hidden layers possess a log-sigmoid transfer function while the neurons of the output layer have a linear transfer function for approximating the networks outputs, however, the nodes of the input layer do not make use of any transfer functions. The neural network toolbox of MATLAB version 9.1 (Mathworks, Inc, 2016) was used to perform the ANN modelling of the microwave drying process. The MATLAB scripts for the ANN modelling have been reported earlier (Omotola and Agbede, 2022).

3. RESULTS AND DISCUSSION

3.1. Microwave Drying Characteristics of Banana Peels

Figure 1a shows the influence of microwave power on the drying behavior of banana peel slices. The moisture ratio decreased with time as the microwave drying progressed indicating that moisture was continuously removed from the peels during the drying operation. It was also observed that the drying rate of banana peel slices increased with increasing microwave power; drying times of 110, 60, 40, 24 and 12 min were required to completely remove moisture from the peel slices at 200, 400, 600, 800 and 1000 W, respectively. This implies that the microwave drying rate of banana peels can be enhanced by drying at higher microwave power. Similarly, Figure 1b indicates that the drying rate of the banana peel slices increased with increasing microwave power; the highest drying rates of 1.810, 0.599, 0.253, 0.198 and 0.103 g water / g dry matter. min were observed at 200, 400, 600, 800 and 1000 W, respectively. The higher drying rates achieved at higher microwave power were due to the larger thermal energy generated by higher microwave energy available at elevated microwave power levels which resulted in a more rapid evaporation of moisture from the banana peel slices (Chandrasekaran, *et al*., 2013). An increase in drying rate with increasing microwave power has been reported for the microwave drying of green microalgae paste biomass (Agbede *et al*., 2020a), mint leaves (Özbek and Dadali, 2007), spinach (Ozkan *et al*., 2007), turmeric slices (Surendhar *et al*., 2019), coriander (Sarimeseli, 2011) and basil (Demirhan and Özbek, 2009).

A slight increase in the drying rate, an initial warming up period, was observed during the microwave drying at 200, 400, 600 and 800 W; nevertheless, the microwave drying of the banana peels occurred mainly in the falling rate period and thus was controlled by the diffusion of moisture from the inner part of the peel to its surface. Agbede et al. (2020a), Agbede et al. (2021) and Evin (2012) have previously observed a short initial warming up period followed by a main falling rate period during the microwave drying of green microalgae paste biomass, banana stalk biomass and *Gundelia tournefortii,* respectively.



(a) (b)

Figure 1: (a) Plot of moisture ratio versus drying time for microwave drying of banana peel slices, (b) Plot of drying rate versus drying time for microwave drying of banana peel slices

3.2. Effective Moisture Diffusivities and Activation Energy

The effective moisture diffusivities for the microwave drying of banana peel biomass at 200 – 1000 W were 1.26 x 10^{-9} – 1.83 x 10^{-8} m^2 s^{-1} as shown in Figure 2. The effective moisture diffusivity increased with increasing microwave power since the activity of moisture in the banana peel slices increased owing to the higher heating rate at higher microwave power resulting in larger moisture diffusivities. The effective moisture diffusivities of 1.26 x 10^{-9} – 1.83 x 10^{-8} m^2 s^{-1} for the microwave drying of banana peels obtained in this study are within the range of 10^{-12} – 10^{-6} m^2 s^{-1} previously reported for agro-products (Erbay and Icier, 2010). They are lower than 5.5 × 10^{-8} - 3.5 × 10^{-7} m^2 s^{-1}, 8.315 x 10^{-8} - 2.363 x 10^{-7} and 5.5 × 10^{-8} - 3.5 × 10^{-7} m^2 s^{-1} reported for the microwave drying of *Gundelia tournefortii* (Evin, 2012), green pepper (Darvishi *et al.*, 2014) and *Gundelia tournefortii* (Evin, 2012), respectively. However, they are larger than those of 6.3 x 10^{-11} - 2.19 x 10^{-10} m^2 s^{-1}, 2.168 x 10^{-10} - 7.899 x 10^{-10} and 3.982 x 10^{-11} - 2.073 x 10^{-10} for the microwave drying of coriander leaves (Sarimeseli, 2011), basil leaves (Demirhan and Özbek, 2009) and mint leaves (Özbek and Dadali, 2007), respectively.

The effective moisture diffusivity was well described by the Arrhenius-type relationship of Equation (10), the activation energy for microwave drying of the banana peels biomass was 129 W g^{-1}. This energy is a measure of the energy required to initiate diffusion of moisture from the inner part of the banana peel to its surface. The measured activation energy of 129 W g^{-1} for microwave drying of banana peel biomass is very close to that of 122 W g^{-1} earlier reported for the microwave drying of banana stalk biomass. However, it is much larger than those of 39.32, 21.40, 14.19, 12.28 and 10.43 previously reported for the microwave drying of turmeric slices (Surendhar *et al.*, 2019), microalgae paste (Agbede *et al.*, 2020a), green pepper (Darvishi *et al.*, 2014), mint leaves (Özbek and Dadali, 2007) and basil leaves (Demirhan and Özbek, 2009), respectively.

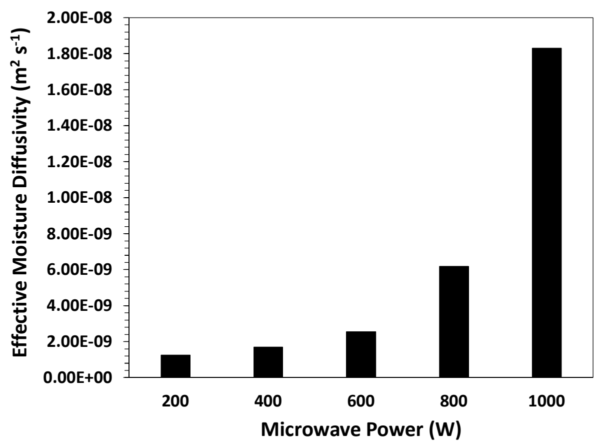
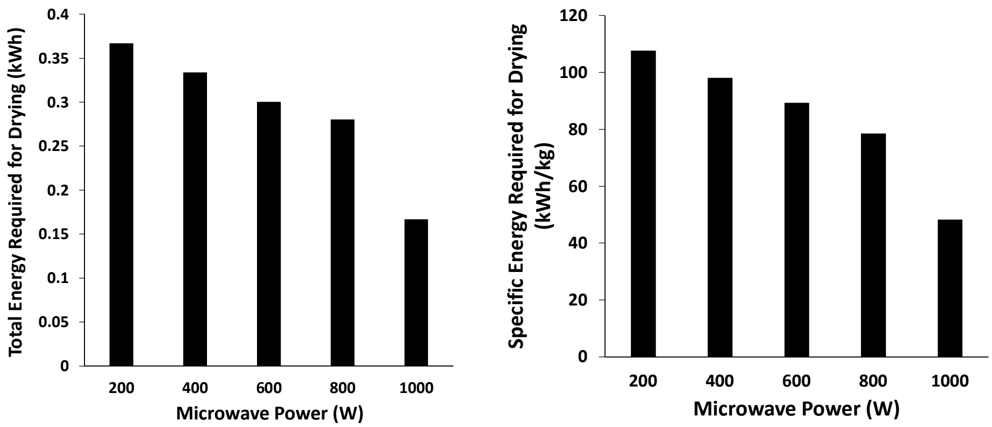


Figure 2: Plot of effective moisture diffusivity versus microwave power for the microwave drying of banana peels

3.3. Banana Peel Microwave Drying Energy Requirement

The total and specific energies required for the microwave drying of banana peel slices at 200 – 1000 W were 0.37 – 0.17 kWh and 107.5 – 48.2 kWh/kg water removed, respectively, as shown in Figure 3. The total and specific energies required for drying the banana peel slices decreased with increasing microwave power, suggesting that the energy required for drying the biomass may be reduced by drying at higher microwave power levels. A decrease in energy consumption during microwave drying with increasing microwave power has been previously observed during the microwave drying of turmeric slices (Surendhar *et al.*, 2019) and microalgae paste (Agbede *et al.*, 2020a). The specific energies of 107.5 – 48.2 kWh/kg water removed, required for the microwave drying of banana peel slices at 200 – 1000 W are higher than those of 51 – 34.8 kWh/kg, 34.9 - 26.2 kWh/kg and 6.84 – 2.72 kWh/kg required for microwave drying of banana stalk slices at 400 – 1000 W (Agbede et al., 2021), microalgae paste at 450 - 700 W (Agbede et al., 2020a) and turmeric slices at 270 – 900 W (Surendhar *et al*., 2019), respectively.



(a) (b)

Figure 3: (a) Total energy required for drying banana peel biomass at 200 – 1000 W (b) Specific energy required for drying banana peel biomass at 200 – 1000 W

3.4. Mathematical Modelling of the Thin Layer Microwave Drying of Banana Peel

Table 2, Table 3, Table 4, Table 5 and Table 6 detail the statistical parameters and model constants obtained when the twelve mathematical models in Table 1 were fitted to the experimental microwave drying data. The Weibull model had the highest R^2 value and the lowest SSE, RMSE and χ^2 values at each of the operating microwave power levels compared to the other eleven models. The R^2 values obtained when experimental data were fitted to the Weibull model were in the range 0.991 – 1.000, while the SSE, RMSE and χ^2 values were in the ranges 3.477 x 10^{-5} – 0013, 0.0007 – 0.0361 and 5.643 x 10^{-5} – 0.00106, respectively. Similarly, Figure 4, which is a plot of moisture ratio predicted by the Weibull model against the experimental moisture ratio for the microwave drying of banana peels at 200 – 1000 W, shows that the moisture ratio predicted by the Weibull model truly matched the experimental data. The Weibull model was considered to best describe the kinetics of the thin layer microwave drying of banana peel slices since this model best fitted the microwave drying data. The Weibull model has been reported to best describe the microwave drying kinetics of mussels (Kipcak, 2017) and banana stalk biomass (Agbede et al., 2021).

Table 2: Model constants and statistical parameters obtained when mathematical models were fitted to the experimental data for the microwave drying of banana peel biomass at 200 W

Model	Model constant	R^2	SSE	RMSE	χ^2
Midilli-kucuk	a=0.997, b=0, k=0.004, n=1.489	0.995	0.0010	0.0010	0.00098
Page	k=0.004, n=1.503	0.993	0.0012	0.0012	0.00144
Logarithmic	a=1.303, c=-0.259, k=0.17	0.990	0.3311	0.3310	0.42142
Two- term	a=0.542, b=0.542, k_0=0.028, k_1=0.028	0.969	0.0044	0.0039	0.00613
Wang and Singh	a=-0.018, b= 8.10 x10^{-5}	0.993	0.0014	0.0011	0.00133
Approximation of diffusion	a=1, b=1, k=0.025	0.960	0.0057	0.0057	0.00722
Modified Henderson and Pabis	a=0.361, b=0.361, c=0.361, g=0.028, h=0.028, k=0.028	0.969	0.0044	0.0039	0.00766
Modified page	k=0.291, n=1.545, k_0=4.41x10^{-17}	0.182	0.2116	0.2116	0.24692
Henderson and Pabis	a=1.84, k=0.028	0.969	0.0044	0.0039	0.00511
Two-term exponential	a=0.981, k=1	0.960	0.2447	0.2447	0.28549
Verma et al	a=6.303, g=0.055, k=0.047	0.990	0.0014	0.0014	0.00178
Weibull	a=-0.053, b= -1.0311 k=0.004, n=1.457	0.995	0.0007	0.0007	0.00104

Table 3: Model constants and statistical parameters obtained when mathematical models were fitted to the experimental data for the microwave drying of banana peel biomass at 400 W

Model	Model constant	R^2	SSE	RMSE	χ^2
Midilli-kucuk	a=1, b=3.84x10^{-5}, k=0.137, n=0.99	1.000	3.663 x 10^{-5}	0.0061	8.548 x 10^{-5}
Page	K=0.141, n=0.997	1.000	8.728 x 10^{-5}	0.0093	0.00012
Logarithmic	a=0.997, c=-0.003, k=0.135	1.000	3.483 x 10^{-5}	0.0059	6.095 x 10^{-5}
Two- term	a=0.5, b=0.5,k0=0.134, k1=0.134	1.000	3.936 x 10^{-5}	0.0063	9.183 x 10^{-5}
Wang and Singh	a=-0.055, b = 0.001	0.853	0.3702	0.6085	0.5183
Approximation of diffusion	a=1, b=1, k=0.134	1.000	3.936 x 10^{-5}	0.0063	6.89 x 10^{-5}
Modified Henderson and Pabis	a=0.333, b=0.333, c=0.333,g=0.134, h=0.134, k=0.134	1.000	3.947 x 10^{-5}	0.0063	0.00028
Modified Page	k=0.134, n=0.997,	1.000	4.100 x 10^{-5}	0.0064	5.700 x 10^{-5}
Henderson and Pabis	a=1, k=0.134	1.000	3.934 x 10^{-5}	0.0063	5.510 x 10^{-5}
Two-term exponential	a=1, k=0.134	1.000	3.936 x 10^{-5}	0.0063	5.510 x 10^{-5}
Verma et al	a=0.982, g=0.992, k=1	1.000	0.0111	0.1030	0.0186
Weibull	a=-0.003, b-0.997 k=0.133, n=1.006	1.000	3.477 x 10^{-5}	0.0059	8.114 x 10^{-5}

Table 4: Model constants and statistical parameters obtained when mathematical models were fitted to the experimental data for the microwave drying of banana peel biomass at 600 W

Model	Model constant	R^2	SSE	RMSE	χ^2
Midilli-kucuk	a=0.999, b=0, k=0.006, n=1.92	1.000	6.823×10^{-5}	0.0083	0.00020
Page	k=0.006, n=1.933	1.000	0.0001	0.0119	0.00014
Logarithmic	a=1.334, c=-0.268, k=0.047	0.969	0.0052	0.0718	0.00619
Two-term	a=0.548, b=0.548, k_0=0.075, k_1=0.075	0.943	0.0095	0.0977	0.01430
Wang and Singh	a=-0.051, b=0.001	0.975	0.0851	0.2918	0.08513
Approximation of diffusion	a=1, b=1, k=0.068	0.931	0.0116	0.1076	0.01388
Modified Henderson and Pabis	a=0.365, b=0.365, c=0.365, g=0.075, h=0.075, k=0.075	1.000	0.0095	0.0977	0.02861
Modified page	k=0.381, n=4.13×10^{-7},	0.366	0.1057	0.3250	0.10565
Henderson and Pabis	a=1.095, k=0.075	0.943	0.0095	0.0977	0.0095
Two-term exponential	a=1, k=0.068	0.931	0.1159	0.1076	0.0116
Verma et al	a=6.629, g=0.195, k=0.157	0.996	0.0006	0.0254	0.00077
Weibull	a=-0.009, b=-1.009 k=0.006, n=1.909	1.000	3.762×10^{-5}	0.0061	5.643×10^{-5}

Table 5: Model constants and statistical parameters obtained when mathematical models were fitted to the experimental data for the microwave drying of banana peel biomass at 800 W

Model	Model constant	R^2	SSE	RMSE	χ^2
Midilli-kucuk	a=0.996, b=0.002, k=0.01, n=1.928	0.991	0.0014	0.0376	0.00255
Page	k=0.012, n=1.894	0.987	0.0018	0.0419	0.00225
Logarithmic	a=1.606, c=-0.554, k=0.051	0.974	0.0035	0.0594	0.00529
Two- term	a=0.55, b=0.55, k_0=0.111, k_1=0.111	0.926	0.0100	0.0999	0.01798
Wang and Singh	a=-0.07, b=0.001	0.976	0.0036	0.0602	0.00467
Approximation of diffusion	a=1, b=1, k=0.103	0.914	0.0116	0.1077	0.01749
Modified Henderson and Pabis	a=0.367, b=0.367, c=0.367, g=0.111, h=0.111, k=0.111	0.926	0.0100	0.1000	0.02998
Modified page	k=0.135, n=5.34×10^{-7}	0.325	0.0915	0.3025	0.11763
Henderson and Pabis	a=1.1, k=0.111	0.926	0.0100	0.0999	0.01284
Two-term exponential	a=1, k=0.103	0.914	0.0116	0.1077	0.01492
Verma et al	a=10.729, g=0.241, k=0.215	0.975	0.0034	0.0579	0.00503
Weibull	a=-0.045, b=-1.0121 k=0.01, n=1.883	0.991	0.0013	0.0361	0.00106

Table 6: Model constants and statistical parameters obtained when mathematical models were fitted to the experimental data for the microwave drying of banana peel biomass at 1000 W

Model	Model constant	R^2	SSE	RMSE	χ^2
Midilli-kucuk	A=0.999, b=-0.001, k=0.409, n=1.023	0.999	9.2819×10^{-5}	0.0096	0.00022
Page	K=0.397, n=1.069	0.999	0.0001	0.0612	0.00019
Logarithmic	a=1.018, c=-0.018, k=0.408	0.999	7.823×10^{-5}	0.0088	0.00014
Two- term	a=0.501, b=0.501, k_0=0.431, k_1=0.431	0.998	0.0002	0.0134	0.00042
Wang and Singh	a=-0.244, b=0.014	0.956	0.0052	0.0723	0.0072
Approximation of diffusion	a=1, b=1, k=0.43	0.998	0.3332	0.0135	0.3333
Modified Henderson and Pabis	a=0.334, b=0.334, c=0.334,g=0.431, h=0.431, k=0.431	0.998	0.0002	0.0134	0.0013
Modified Page	k=0.421, n=1.069	0.999	0.0001	0.0116	0.00019
Henderson and Pabis	a=1.002, k=0.431	0.998	0.0002	0.0134	0.00025
Two-term exponential	a=1, k=0.996	0.998	0.0170	0.1304	0.02379
Verma et al	a=2.911, g=0.617, k=0.539	0.999	0.0001	0.0113	0.00022
Weibull	a=-0.018, b=-1.017 k=0.407, n=1.003	0.999	7.813×10^{-5}	0.0088	0.00018

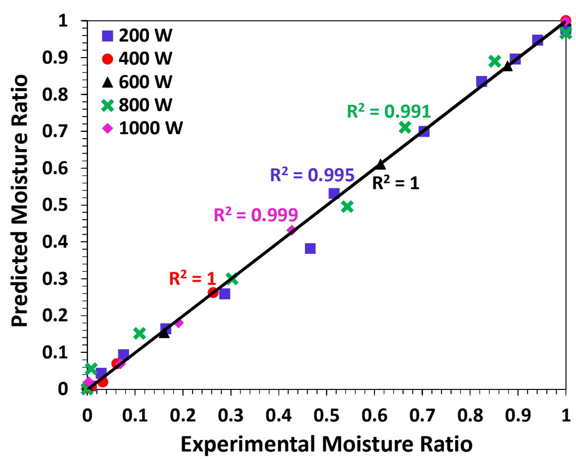


Figure 4: Plot of moisture ratio predicted by the Weibull model versus experimental moisture ratio at 200 – 1000 W

3.5. ANN Modelling of Microwave Drying Kinetics of Banana Peel

Table 7 presents the effect of number of hidden layers and neurons on the accuracy of ANNs modelling the microwave drying behavior of banana peel. The single-hidden layer network with 3 neurons in the hidden-layer stood out as the network with the best performance, reporting the highest correlation coefficients of 0.99903, 0.99978, 0.9999, 0.99989 and 0.99749 with corresponding minimum MSE of 3.1995×10^{-4}, 1.3911×10^{-4}, 4.2044×10^{-4}, 3.3984×10^{-5} and 7.3064×10^{-4} at 200, 400, 600, 800 and 1000 W, respectively. The structure of the selected ANN model is shown in Figure 5. The predicted outputs of the selected ANN model fitted the experimental data points well as seen in Figure 6 (a-e).

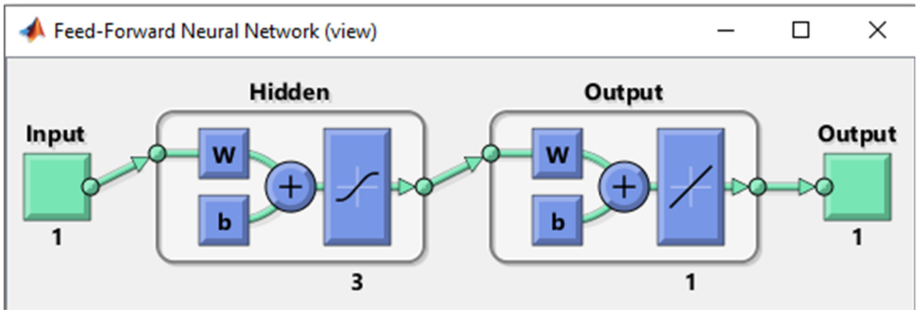
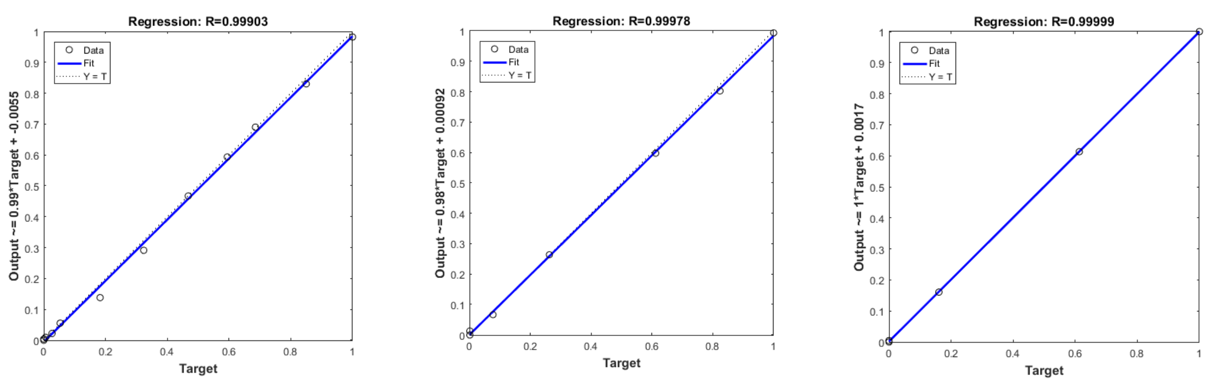


Figure 5: Structure employed for ANN modelling

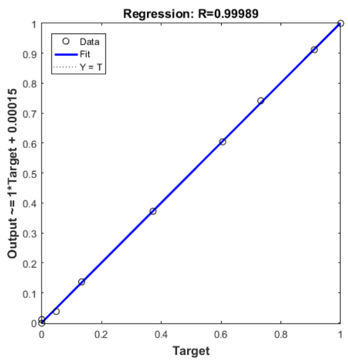
Table 7: Monitoring the effect of number of hidden layers and neurons on the accuracy of ANNs in predicting the microwave drying of banana peel biomass

Number of neurons in hidden layers			200 W		400 W		600 W		800 W		1000 W	
Layer 1	Layer 2	Layer 3	R	MSE	R	MSE	R	MSE	R	MSE	R	MSE
10	-	-	0.97214	0.0076	0.99646	0.0012	0.91599	0..0267	0.95852	0.0303	0.71547	0.2274
5	5	-	0.99539	0.0012	0.99694	0.0013	0.99733	0.0011	0.9996	1.2114 x 10^{-}	0.1025	0.2153
4	3	3	0.99918	3.0173 x 10^{-4}	0.99073	0.0044	0.87403	0.0437	0.9872	0.0061	0.33284	0.0061
5	-	-	0.99322	0.0019	0.99523	0.0024	0.87884	0.0577	0.93755	0.1761	0.9864	0.0065
3	2	-	0.99236	0.0034	0.79215	0.1718	0.99049	0.0089	0.99988	4.9607 x 10^{-}	0.99982	4.6295 x 10^{-5}
2	2	1	0.99679	9.4271 x 10^{-4}	0.98029	0.0088	0.4991	0.3103	0.97622	0.0067	0.35687	0.1257
3	-	-	0.99903	3.1995 x 10^{-4}	0.99978	1.3911 x 10^{-}	0.9999	4.2044 x 10^{-4}	0.99989	3.3984 x 10^{-}	0.99749	7.3064 x 10^{-4}
2	1	-	0.99855	4.6892 x 10^{-4}	0.12842	0.2839	0.94267	0.0344	0.89712	0.0284	-0.32982	0.1751
1	1	1	0.81522	0.0432	0.99736	0.0032	0.99201	0.0036	0.99818	9.1079 x 10^{-}	0.98708	0.0311
2	-	-	0.99951	1.3345 x 10^{-4}	0.99316	0.0026	0.81735	0.2013	0.99809	5.6329 x 10^{-}	0.99439	0.0018
1	1	-	0.99716	8.6925 x 10^{-4}	0.99794	0.0012	0.99539	0.0020	0.99689	0.0158	0.94284	0.0
1	-	-	0.99644	0.0018	0.99763	0.0035	0.96505	0.0162	0.99776	0.0011	0.99815	0.0114

(a) (b) (c)



(d)



(e)

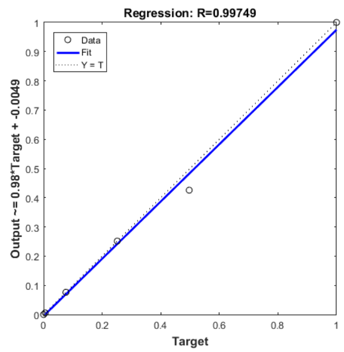


Figure 6: Predicted moisture ratio by the selected ANN model versus experimental (target) values for the microwave drying of banana peel slices at (a) 200 W (b) 400 W (c) 600 W (d) 800W (e) 1000 W

3.6. Comparison of Mathematical and ANN Modelling

In order to compare the modelling techniques, the coefficient of determination (R^2) of the selected ANN models were calculated from the sample correlation coefficient (R) reported between their corresponding target and output data. A comparison of the selected mathematical (Weibull) and ANN models that best described the drying behavior of banana peel is presented in Table 8. Generally, both models reported R^2 values that were ≥ 0.991 and MSE (SSE) values that were ≤ 0.0013. Also, as previously discussed, both model well described the drying kinetics of banana peel biomass. Specifically, in comparison, at 200 W, the ANN model reported a higher R^2 of 0.998 and lower MSE of 3.1995 x 10^{-4} relative to R^2 of 0.995 and MSE of 0.0007 reported by the Weibull model. Likewise, at 800 W, the ANN model reported a higher R^2 of 1.000 and lower MSE of 3.3984 x 10^{-5} relative to R^2 of 0.991 and MSE of 0.0013 reported by the Weibull model. Though both the Weibull and ANN models had exactly the same R^2 value of 1.000 at 400 and 600 W, the Weibull model had MSE values of 3.477 x 10^{-5} and 3.762 x 10^{-5} at 400 and 600 W, respectively that were lower than those of 1.3911 x 10^{-4} and 4.2044 x 10^{-4} at 400 and 600 W, respectively, reported by the ANN model. On the other hand, for microwave drying at 1000 W, the mathematical (Weibull) model reported a R^2 (0.999) higher than that of the ANN model (0.995), and a MSE value (7.813 x 10^{-5}) lower than that (7.3064 x 10^{-4}) of the ANN model. These results indicate that the ANN model may not yield a better result than the mathematical (Weibull) model in terms of accuracy, however it is superior to the mathematical model in generalization ability (Aghbashlo et al., 2015).

Table 8: Comparison of modelling techniques for microwave drying of banana peel biomass

Drying condition	ANN model			Mathematical (Weibull) model	
	R	R^2	MSE	R^2	MSE
200 W	0.99903	0.998	3.1995 x 10^{-4}	0.995	0.0007
400 W	0.99978	1.000	1.3911 x 10^{-4}	1.000	3.477 x 10^{-5}
600 W	0.9999	1.000	4.2044 x 10^{-4}	1.000	3.762 x 10^{-5}
800 W	0.99989	1.000	3.3984 x 10^{-5}	0.991	0.0013
1000 W	0.99749	0.995	7.3064 x 10^{-4}	0.999	7.813 x 10^{-5}

4. CONCLUSION

The microwave drying of banana peel biomass was investigated. The drying rate of the peel and the effective moisture diffusivity were considerably enhanced by drying at higher microwave power levels. Also, the energy required for microwave drying can be lowered by drying at higher microwave power levels. Microwave drying of banana peel took place mainly in the falling rate period and was controlled by diffusion of moisture from the inner part of the peel to its surface. The microwave power dependence of the effective moisture diffusivity for microwave drying of banana peel biomass was aptly described by an Arrhenius-type relationship with an activation energy of 129 W g^{-1}. The Weibull mathematical model for thin layer drying most suitably described the microwave drying kinetics of banana peel biomass. The ANN model consisting of a single-hidden layer network with 3 neurons in the hidden-layer also best predicted the microwave drying kinetics of the peel. Both the Weibull and ANN model well described the drying kinetics of banana peel biomass. Though the ANN model may not yield a better result than the mathematical (Weibull) model in terms of accuracy, it is superior to the mathematical model in generalization ability.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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